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DISTRIBUTION, COEXISTENCE, AND DECLINE OF MOROCCAN LARGE BRANCHIOPODS

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ABSTRACT

An extensive field survey was conducted between 2012 and 2014 to update the knowledge on the diversity and distribution of large branchiopods in northwestern Morocco. Historical data were available from the 1980s to allow comparison with our current survey, but most exact locations of previously sampled large branchiopod populations were unknown. Fifteen (of the known 17) Moroccan large branchiopod species (9 Anostraca, 3 Notostraca, and 3 Spinicaudata) were recovered during our survey, including two endemic species for Morocco (*Linderiella africana* and *Tanymastigites brteki*). When comparing our results with historical data, a general decline in habitat numbers and species richness per habitat over the last 30 years becomes apparent. Although northwestern Morocco can still be considered a hotspot for large branchiopods, conservation measures should be taken to prevent further loss of biodiversity.

KEY WORDS: biodiversity loss, conservation, Mediterranean temporary wetlands

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INTRODUCTION

Large branchiopods (Anostraca, Notostraca, Laevidaudata, Spinicaudata, and Cyclestheria) are highly adapted to temporary aquatic systems (Brendonck et al., 2008) and are often considered to be the flagship group of these habitats (Belk, 1998). They can survive in these extreme habitats by having a short life cycle and producing drought-resistant dormant eggs (Brendonck, 1996). While these crustaceans occur on all continents, they achieve their highest diversity in arid and semi-arid climates (Brendonck et al., 2008). The Mediterranean climate is characterized by dry summers and mild, wet winters, resulting in ideal conditions for the formation of temporary ponds (Grillas et al., 2004). Although Mediterranean temporary ponds (MTP) are generally small (ranging from a few m^2 to 10 ha) and shallow (often only a few centimeters deep), they are biodiversity hotspots housing diverse floral and faunal communities (Grillas et al., 2004). Unfortunately, MTP are highly threatened habitats due to growing anthropogenic pressure, with agriculture and urban development resulting in the destruction, hydrological modification, eutrophication and pollution of these vulnerable habitats. Their numbers are rapidly declining on a global scale, with loss rates ranging from 23% to 97% in the last century (Weir and Bauder, 1990; King, 1998; Gallego-Fernandez et al., 1999; Rhazi et al., 2012). Due to the reduction in quantity and quality of their habitats, several large branchiopod species have become endangered (Brendonck et al., 2008). However, the lack of information on the diversity and distribution patterns of large branchiopods in certain regions, including large parts of Africa, makes it difficult to assess their conservation status.

Despite the losses of MTP in general, Morocco was at least until the end of the 1980s characterized by an abundance of MTP (locally called dayas) that are scattered throughout the landscape from the coastal plains to the high mountain areas (Thiéry, 1987). These temporary ponds are endorheic depressions that are filled by rainfall and dry out through soil infiltration and evaporation. Inundation usually takes place from November (depending on the rather unpredictable onset of the rainy season) until May (depending on temperature and the size and depth of the pond basins). Unfortunately, similar to other regions in the Mediterranean region, many of these temporary ponds are heavily degraded or have been destroyed due to growing anthropogenic pressure and the negative perception of these ecosystems by the local people (e.g., as wasted land or mosquito habitats) (Bouahim et al., 2011). A case study in the province of Ben Slimane showed a decline of 23% in number and 61% in total surface area of MTP over a period of 50 years, mostly due to agriculture and urbanization (Rhazi et al., 2012). However, the impacts of these losses on biodiversity remain unknown.

The conservation issues of MTP have only recently been gaining attention, with MTP now being included as priority habitats under the Habitat Directive in the EU (Natura Code 3170, 92/43/CCE). In Morocco, however, MTP do not enjoy such protection status. In addition, knowledge of current

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large branchiopod distributions is lacking. To address this problem, an extensive large branchiopod survey was conducted in 2012-2014 in northwestern Morocco, where rainfall is sufficient for the formation of an abundance of MTP. The goal of this study was to map current large branchiopod distribution and coexistence patterns and to quantify population and species losses over time by comparing our findings to historical data (Fadli, 1987; Thiéry, 1987, 1991).

MATERIALS AND METHODS

A total of 122 temporary ponds were selected for the survey, based on historical data on large branchiopod distributions (Fadli, 1987; Thiéry, 1987) and focusing on regions with high densities of MTP (Rhazi et al., 2012). Where possible, we attempted to find the exact location of ponds that were sampled in previous studies using site descriptions and satellite images from Google Earth (2014). The study regions covered all three main Mediterranean bioclimatic zones (arid, semi-arid and humid), and spanned a 600 km range (from Tangier in the North to Essaouira in the South) and an altitudinal gradient from just above sea-level to 2500 m a.s.l.

Study Regions

Rif.—The most northern part of Morocco is a mainly mountainous region, in which 18 ponds were sampled between 2 m and 1386 m of altitude. Mean annual rainfall is 891 mm and mean air temperature is 16.5°C, resulting in a humid climate. The natural vegetation consists of cork oak (*Quercus suber*), Portuguese oak (*Q. faginea*), Pyrenean oak (*Q. pyrenaica*), maritime pine (*Pinus pinaster*) and Atlas Cedar (*Cedrus atlantica*). The geological substratum consists of Cretaceous siliceous sandstone and marl with interbedded limestone and Cretaceous flysch.

Middle Atlas.—The mountainous region to the south of Fes is part of the Middle Atlas. This wetter and colder region (mean annual rainfall of 1118 mm and mean air temperature of 11.4°C) has a humid climate with cold winters. Twelve ponds were sampled in this region between 1432 and 1922 m of altitude. The natural forests consist of the Atlas Cedar (*C. atlantica*) and holm oak (*Quercus ilex*), with thorny xerophytes on the mountain top steppes. Basalt and early and middle Jurassic limestone and dolomite form the geological substratum.

Maamora.—The cork oak (*Q. suber*) forest, with some plantations of Australian acacia (*Acacia mearnsii*) and Allepo pine (*P. halepensis*), just north of Rabat, is called the Maamora forest. A total of 16 ponds were sampled here, between 112 and 181 m of altitude. The climate is sub-humid, with a mean annual rainfall of 530 mm and a mean air temperature of 17.5°C. The geological substratum is a Pliocene/Quaternary sand deposit on a clay bedding.

Ben Slimane.—A well-studied area of Morocco is the province of Ben Slimane (between Rabat and Casablanca): about 2% of the land area consists of MTP (Rhazi et al., 2006). The elevation of the 49 sampled ponds ranges from 170 m to 299 m. The climate is semi-arid with an average annual rainfall of 425 mm of and an average annual temperature of 17.4°C. The area mainly consists of natural of cork oak (*Q. suber*) forests and agricultural lands. There are also a few artificial forests of Allepo pine (*P. halepensis*) and *Eucalyptus* spp. around the city of Ben Slimane. The geological substratum primarily consists of quarzitic sandstone.

Chaouia.—South of Casablanca, near Berrechid, are the plains of Chaouia. This region has a semi-arid climate with warm winters, with a mean annual precipitation of 370 mm and temperature of 17.5°C. The region is mainly an arable area due to the dominance of fertile vertisols. It also has a few plantations of *Eucalyptus* spp. and Allepo pine (*P. halepensis*). The region is known as 'la peau de panthère' (translated 'panther skin'), because of its high number of MTP. Twenty ponds in this region were well studied by Thiéry (1991) and the 11 currently remaining ponds are all located between 222 and 233 m of altitude. The substratum is built up of clays, salt, and basalt from the Permian/Triassic and sandstone, sand, conglomerate and lacustrine limestone from the Pliocene/Quaternary.

Jbilets.—The region northwest of Marrakech is called 'Jbilets,' referring to the Arabic name of 'hills.' The nine sampled ponds are located between 290 and 494 m of altitude, and are situated in a mainly dry steppe, sparsely dominated by the Atlas mastic tree (*Pistacia atlantica*) and *Ziziphus lotus*. The geological substratum is sandstonic shale, and the climate is arid, with only 264 mm of precipitation per year, and a mean temperature of 19.6°C.

Essaouira.—The most southern sampled region is located just south of Essaouira, and is a semi-arid region with 340 mm of precipitation and a mean temperature of 17.3°C. Seven ponds were sampled between 75 and 116 m of altitude, in a natural forest mainly predominated by Argan (*Argania spinosa*) and some narrow formations of Barbary thuja (*Tetraclinis articulata*). The geological substratum consists of Jurassic limestone and Cretaceous marl.

Field Sampling

All ponds were sampled two or three times during the wet seasons of 2012-2013 and 2013-2014 (December-April). A dry soil sample containing the egg bank was also taken for each pond during the dry seasons of 2012 or 2013 (July-September). In the Essaouira region, however, only dry soil samples were taken because there was insufficient rainfall to inundate the MTP in this region during our study.

Active large branchiopod assemblages were sampled qualitatively (presence/absence of species). All sub-habitats of the pond were thoroughly sampled using a sweep net (20 cm × 15 cm, mesh size 500 μm). All specimens were identified in the field or stored in 100% ethanol for identification in the lab. They were identified under a backlit stereo microscope (Olympus SZX12) down to species level using Moroccan (Thiéry, 1987), French (Nourisson and Thiéry, 1988) and Spanish (Alonso, 1996) identification guides.

Resting egg bank samples were taken by collecting the upper 3 cm of dry sediment with a core sampler (0.5 cm). Sediment sampling was performed along orthogonal transects on nine locations in each pond. Eight locations were equally distributed along the two longest perpendicular transects, while the ninth location was the deepest estimated point of the pond. We included this point since it is known to contain the largest numbers of resting eggs as communities are concentrated there at the end of the wet season (Brendonck and De Meester, 2003). The sediment was pooled per pond and stored in double plastic bags at room temperature in the dark.

Laboratory Hatching

To ensure hatching of all large branchiopod species in the lab, optimal hatching conditions as described below were previously determined using mixed soil samples of all ponds, but separately for low altitude and high altitude ponds (below and above 1000 m of altitude). These optimal conditions were then used to hatch the large branchiopods of each pond separately.

From each pond, 100 g of dry sediment was distributed in a 2-l aquarium. For the low altitude ponds, 1.5 l deionized water with EPA salts (Weber, 1991) with a conductivity of 500 μS/cm was used to inundate the sediment. An initial food supply of 0.5 ml of *Scenedesmus obliquus* (100,000 cells/ml) was added immediately after inundation. The aquaria were put in incubators at a temperature of 20°C and a light regime starting with six days of constant light, after which a 14 h light/10 h dark regime was installed. The higher altitude ponds were hatched similarly, but using medium with a conductivity of 50 μS/cm and an incubator temperature of 10°C. Every three days during 33 days, the aquaria were checked for newly hatched branchiopods, by filtering the medium over a 30-μm sieve. When the animals were too small for species identification, they were reared separately in 100-ml jars until they could be identified.

To confirm whether all species hatched from the sediment, an extra 100 g of sediment of each pond was checked for resting eggs using the sugar flotation method by Onbé (1978) and Marcus (1990). The sediment was sieved wet (mesh size 125 μm) to remove clay particles. The remaining sediment was mixed in 50-ml vials with a 1:1 sugar solution and centrifuged at 3000 rpm during 3 minutes, after which the supernatant was filtered through a 64-μm mesh. The process was repeated with the residue but with 10 minutes centrifugation time. The isolated large branchiopod eggs were identified using Mura and Thiéry (1986) and Thiéry and Gasc (1991).

Coexistence

To study the coexistence patterns of the different species, we used the Fager's affinity index (Fager, 1957; Southwood, 1966). It allows calculating coexistence frequencies of pairs of species, as described in Maeda-Martínez et al. (1997):

$$I_{\mathrm{AB}} = \left(\frac{2J}{n_{\mathrm{A}} + n_{\mathrm{B}}}\right),$$

where J is the number of joint occurrences, n_A the total number of occurrences of species A, and n_B the total number of occurrences of species B.

Comparison with Historic Data: the Chaouia Region

As a case study, we focused specifically on the Chaouia region. During a three year survey between March 1983 and June 1986, Thiéry (1991) revealed an exceptionally high large branchiopod diversity in this region. By sampling monthly the active assemblages, a total of 11 large branchiopod species was found in 20 ponds and road ditches in an area of 340 km^2. Since exact GPS coordinates of the ponds were not mentioned, we attempted to localize them using the map and descriptions in the study. When the ponds still existed, current large branchiopod assemblages were compared with those of ca. 30 years ago.

RESULTS

Of the total of 122 sampled temporary ponds, 13 ponds did not contain any large branchiopod species. In the remaining 109 ponds (89.3%), at least one and a maximum of six species were found, only in a single pond (pond 89, Table 1). The mean number of coexisting species was 2.7. A total of 15 species was encountered, including nine Anostraca, three Notostraca and three Spinicaudata (Fig. 1). Two endemic species for the country were reported: *Linderiella africana* Thiéry, 1986 and *Tanymastigites brteki* Thiéry, 1986. The most common species was the notostracan *Triops mauritanicus* Ghigi, 1921, which occurred in 59% (72/122) of the ponds. The most commonly occurring anostracan was *Chirocephalus diaphanus* Prévost, 1803, followed by *Tanymastix affinis* Daday, 1910 and *Streptocephalus torvicornis* (Waga, 1842) which were present in 33.6% (41/122), 32% (39/122) and 30.3% (37/122) of the ponds, respectively. The most common spinicaudatan species were *Cyzicus bucheti* Daday, 1913 and *Maghrebestheria maroccana* Thiéry, 1988, present in 19.7% (24/122) and 16.4% (20/122) of the ponds, respectively.

Branchipus schaefferi Fischer, 1834 was the most widely distributed species; it was the only species that occurred in all of the seven study regions. Several species, on the other hand, were restricted to specific regions. These species were often rare and typically also had Fager's affinity indices of zero (Table 2). *Linderiella africana*, for example, was only encountered in the Rif (10 ponds), where it did not coexist with any other large branchiopod species. Also *Lepidurus apus* (Linnaeus, 1758) and *Artemia salina* (Linnaeus, 1758) were only retrieved respectively in one pond in the Middle Atlas region and only once in Lac Salé Zima (a Ramsar protected salt lake situated at 1 km of the city Chemmaia), where they did not share their habitat with other crustaceans. *Branchinecta ferox* (Milne-Edwards, 1840) was only encountered twice in the Middle Atlas, where it coexisted only with *B. schaefferi*. The highest species affinities were found between *T. mauritanicus* and *C. diaphanus* (65%), *S. torvicornis* (61%) and *T. affinis* (61%) (Table 2).

We compared historical data from the Chaouia region. From the original dataset of the 20 ponds and road ditches in Chaouia mentioned in Thiéry (1991), only nine habitats (numbers 4, 5, 7, 8, 9, 11, 12, 15 and 18) still exist. A total of seven species were encountered in the remaining habitats, with the highest number of coexisting species being five (Table 3), compared to a total of 11 species and a coexistence of 10 species in one pond 30 years ago. The average ± SD species richness in the remaining habitats had declined from 4.6 ± 3.02 to 2.6 ± 1.06 species per pond.

DISCUSSION

This study is the first attempt to update the knowledge on the current diversity and distribution of large branchiopods in Northwestern Morocco, since Thiéry (1987, 1991, 1996) and Fadli (1987). The 15 rediscovered species cover 88.2% (15/17) of the previously recorded Moroccan species. Comparing with other neighboring Mediterranean regions, Morocco has a comparable number of large branchiopod species: 19 species in Algeria (Samraoui and Chakri, 2006), 11 in Tunisia (Turki and Turki, 2010), 19 in Spain (Boix et al., 2007; Diaz-Paniagua et al., 2010; Gascón et al., 2012) and 11 in Southern Portugal (Cancela da Fonseca et al., 2008; Gascón et al., 2012). The current distribution patterns of the Moroccan large branchiopod species are generally in line with the findings of Thiéry (1987). *Tr. mauritanicus* was recovered in all regions except Jbilets, while *T. granarius* (Lucas, 1864) was restricted to the arid regions (South of Casablanca). *Tanymastigites brteki* was recovered in the coastal regions and the Middle Atlas, while *S. torvicornis* was only retrieved in the coastal regions, often in coexistence with *C. bucheti* and *M. maroccana*. However, some species distributions differed from historical patterns in several aspects. It is, however, important to note that Thiéry (1987) also surveyed large branchiopods in the East (Plateau du Rekkam, Hauts-Plateaux, Plaine du Tamlet, Synclinal de Gourrama) and Southeast (Tiznit, Guoulimine, Assa, Mhamid) of Morocco, while this study focused on the Northwestern part. In addition, since detailed information on the exact location of the populations was missing for the majority of the ponds and several ponds seemed to have been destroyed over the years, not all the ponds from Thiéry (1987) could be sampled again in this study.

While *B. schaefferi* was the most commonly occurring species in the study of Thiéry (1987), we found more populations of *C. diaphanus*. However, this may be a result of a more extensive sampling campaign in the province of Benslimane where *C. diaphanus* occurred in 71% (35/49) of the sampled ponds. Nonetheless, *B. schaefferi* is the only species that occurred in all studied regions, which reconfirms its wide distribution as reported by Thiéry (1987). *Tanymastigites perrieri* (Daday, 1910) (originally wrongly described as a new species *T. jbiletica*), on the other hand, had a very restricted distribution area, with only four populations in the Jbilets region, where it coexists with *Leptestheria mayeti* Simon, 1885, *Tr. granarius* and *B. schaefferi*. This species was recorded 30 years ago also from other regions (East of Fes) that were not surveyed in our study. *Linderiella africana* was found in the Middle Atlas 30 years ago, but was not recovered from this region during our survey. Since conditions might be harsh and dispersal capacities limited in these high altitude ponds (isolated ponds, few cattle visits transporting eggs from pond to pond), this species may have gone locally extinct. The species was, however, found to be present in the Rif (a previously unstudied region), not coexisting with any other large branchiopod species. The recovery of *B. ferox* is in line with

Table 1. Coexistence and species richness of Moroccan large branchiopods.

Region	Coordinates	Pond number	*Streptocephalus torvicornis*	*Chirocephalus diaphanus*	*Branchipus schaefferi*	*Tanymastix affinis*	*Branchinecta ferox*	*Tanymastigites brteki*	*Tanymastigites perrieri*	*Linderiella africana*	*Artemia salina*	*Triops mauritanicus*	*Triops granarius*	*Lepidurus apus*	*Cyzicus bucheti*	*Maghrebesteria maroccana*	*Leptestheria mayeti*	Species richness
Rif	35°16′11.10″N 5°26′9.12″W	1																0
Rif	35°16′5.52″N 5°25′56.10″W	2																0
Rif	35°6′1.80″N 5°20′9.12″W	3								+								1
Rif	35°1′22.80″N 5°12′24.24″W	4																0
Rif	35°1′21.48″N 5°12′19.26″W	5								+								1
Rif	35°1′7.62″N 4°59′59.46″W	6								+								1
Rif	35°37′27.60″N 5°52′36.96″W	7		+				+				+			+			4
Rif	35°36′50.82″N 5°55′7.98″W	8		+	+			+				+						4
Rif	35°37′23.82″N 5°58′33.84″W	9	+									+			+			3
Rif	35°37′27.72″N 5°58′42.90″W	10	+			+						+						3
Rif	35°1′45.60″N 5°12′35.22″W	11								+								1
Rif	35°1′47.76″N 5°12′30.24″W	12								+								1
Rif	35°1′50.04″N 5°12′29.22″W	13								+								1
Rif	35°1′50.94″N 5°12′30.78″W	14																0
Rif	35°1′47.40″N 5°12′16.62″W	15								+								1
Rif	35°1′51.84″N 5°12′31.38″W	16								+								1
Rif	35°7′42.06″N 5°26′18.72″W	17								+								1
Rif	35°7′30.48″N 5°17′21.90″W	18								+								1
Middle Atlas	33°37′37.74″N 5°22′27.72″W	19																0
Middle Atlas	33°34′57.60″N 5°21′37.08″W	20																0
Middle Atlas	33°29′55.74″N 5°16′33.72″W	21			+			+				+						3
Middle Atlas	33°29′58.44″N 5°16′32.94″W	22		+	+							+						3
Middle Atlas	33°22′4.14″N 5°8′53.04″W	23																0
Middle Atlas	33°23′15.36″N 5°8′0.78″W	24																0
Middle Atlas	33°24′22.14″N 5°6′59.34″W	25			+			+										2
Middle Atlas	33°24′20.22″N 5°7′21.72″W	26			+		+	+										3
Middle Atlas	33°30′36.90″N 5°8′10.44″W	27					+	+										2
Middle Atlas	33°29′11.46″N 5°7′52.38″W	28																0
Middle Atlas	33°17′18.06″N 5°10′44.46″W	29												+				1
Middle Atlas	33°18′44.88″N 5°3′56.04″W	30		+		+												2
Maamora	34°1′47.34″N 6°41′18.24″W	31				+						+				+		3
Maamora	34°1′37.92″N 6°41′10.14″W	32	+									+						2
Maamora	34°1′6.96″N 6°41′50.10″W	33	+									+						2
Maamora	34°1′16.14″N 6°41′47.88″W	34	+		+	+										+		4

Table 1. (Continued.)

Region	Coordinates	Pond number	*Streptocephalus torvicornis*	*Chirocephalus diaphanus*	*Branchipus schaefferi*	*Tanymastix affinis*	*Branchinecta ferox*	*Tanymastigites brteki*	*Tanymastigites perrieri*	*Linderiella africana*	*Artemia salina*	*Triops mauritanicus*	*Triops granarius*	*Lepidurus apus*	*Cyzicus bucheti*	*Maghrebesteria maroccana*	*Leptestheria mayeti*	Species richness
Maamora	34°1′17.70″N 6°41′49.74″W	35	+			+										+		3
Maamora	34°1′20.28″N 6°41′51.42″W	36	+	+		+						+						4
Maamora	34°0′57.36″N 6°36′37.38″W	37	+									+			+			3
Maamora	34°0′54.30″N 6°36′41.70″W	38	+			+						+				+		4
Maamora	34°0′39.96″N 6°35′52.32″W	39	+									+			+			3
Maamora	34°0′25.32″N 6°36′7.86″W	40													+	+		2
Maamora	34°0′29.52″N 6°36′8.16″W	41	+									+				+		3
Maamora	34°0′24.24″N 6°36′13.98″W	42	+									+						2
Maamora	34°0′51.24″N 6°35′44.28″W	43	+									+						2
Maamora	34°0′59.94″N 6°34′15.06″W	44										+						1
Maamora	34°0′45.12″N 6°34′43.08″W	45													+			1
Maamora	34°0′50.64″N 6°34′44.22″W	46			+	+						+				+		4
Essaouira	31°25′45.30″N 9°43′21.54″W	47																0
Essaouira	31°42′8.70″N 9°43′55.44″W	48																0
Essaouira	31°23′56.22″N 9°44′0.90″W	49																0
Essaouira	31°23′6.12″N 9°42′58.80″W	50			+													1
Essaouira	31°23′16.08″N 9°42′45.54″W	51			+							+					+	3
Essaouira	31°25′52.38″N 9°43′24.90″W	52																0
Essaouira	31°23′4.86″N 9°42′31.56″W	53			+	+												
Chaouia	33°12′45.06″N 7°49′13.38″W	54	+									+						2
Chaouia	33°12′7.02″N 7°51′27.54″W	55	+									+						2
Chaouia	33°11′23.76″N 7°52′6.36″W	56	+									+						2
Chaouia	33°11′7.68″N 7°52′24.72″W	57	+					+				+			+			4
Chaouia	33°10′41.82″N 7°52′27.36″W	58	+									+			+			3
Chaouia	33°8′6.84″N 7°53′51.18″W	59	+		+			+				+						4
Chaouia	33°7′36.90″N 7°54′50.34″W	60										+						1
Chaouia	33°11′57.90″N 7°51′43.98″W	61	+					+				+	+		+			5
Chaouia	33°12′48.42″N 7°47′52.86″W	62		+								+						2
Chaouia	33°14′18.54″N 7°46′23.64″W	63	+									+	+					3

Table 1. (Continued.)

Region	Coordinates	Pond number	*Streptocephalus torvicornis*	*Chirocephalus diaphanus*	*Branchipus schaefferi*	*Tanymastix affinis*	*Branchinecta ferox*	*Tanymastigites brteki*	*Tanymastigites perrieri*	*Linderiella africana*	*Artemia salina*	*Triops mauritanicus*	*Triops granarius*	*Lepidurus apus*	*Cyzicus bucheti*	*Maghrebesteria maroccana*	*Leptestheria mayeti*	Species richness
Chaouia	33°11′22.02″N 7°51′19.98″W	64	+									+						2
Jbilets	31°49′23.64″N 8°32′30.30″W	65			+				+									2
Jbilets	31°49′17.94″N 8°32′30.42″W	66							+									1
Jbilets	31°58′45.18″N 8°22′35.82″W	67			+								+					2
Jbilets	31°59′9.00″N 8°23′6.18″W	68			+								+					2
Jbilets	31°56′27.18″N 8°23′54.06″W	69			+				+				+				+	4
Jbilets	31°52′32.52″N 8°28′58.20″W	70			+													1
Jbilets	31°52′46.32″N 8°29′35.76″W	71			+								+				+	3
Jbilets	31°45′9.36″N 8°37′9.36″W	72							+									1
Jbilets	32°5′23.94″N 8°41′17.76″W	73									+							1
Ben Slimane	33°35′7.74″N 6°55′31.44″W	74	+										+		+			3
Ben Slimane	33°35′52.08″N 6°54′3.90″W	75		+														1
Ben Slimane	33°36′8.10″N 6°54′17.94″W	76	+	+								+						3
Ben Slimane	33°34′31.14″N 6°51′42.66″W	77													+			1
Ben Slimane	33°33′27.90″N 6°52′13.20″W	78	+	+								+			+			4
Ben Slimane	33°33′3.96″N 6°51′38.88″W	79		+														1
Ben Slimane	33°33′3.06″N 6°51′20.64″W	80		+											+			2
Ben Slimane	33°34′2.22″N 6°51′48.96″W	81		+								+						2
Ben Slimane	33°41′42.30″N 7°9′0.42″W	82	+	+								+			+			4
Ben Slimane	33°41′34.08″N 7°9′1.74″W	83		+								+			+			3
Ben Slimane	33°38′25.50″N 7°8′43.38″W	84	+	+								+			+			4
Ben Slimane	33°38′9.18″N 7°8′45.90″W	85										+				+		2
Ben Slimane	33°37′27.48″N 7°10′30.30″W	86				+						+				+		3
Ben Slimane	33°37′12.72″N 7°10′32.58″W	87				+												1
Ben Slimane	33°37′46.26″N 7°10′15.60″W	88		+		+						+				+		4
Ben Slimane	33°37′51.96″N 7°9′54.66″W	89	+	+		+						+			+	+		6
Ben Slimane	33°37′33.06″N 7°9′54.66″W	90	+	+		+						+				+		5
Ben Slimane	33°37′15.72″N 7°10′11.04″W	91		+		+						+			+			4
Ben Slimane	33°37′17.22″N 7°9′32.16″W	92		+								+						2

Table 1. (Continued.)

Region	Coordinates	Pond number	*Streptocephalus torvicornis*	*Chirocephalus diaphanus*	*Branchipus schaefferi*	*Tanymastix affinis*	*Branchinecta ferox*	*Tanymastigites brteki*	*Tanymastigites perrieri*	*Linderiella africana*	*Artemia salina*	*Triops mauritanicus*	*Triops granarius*	*Lepidurus apus*	*Cyzicus bucheti*	*Maghrebesteria maroccana*	*Leptestheria mayeti*	Species richness
Ben Slimane	33°37′22.50″N 7°9′17.22″W	93		+		+						+				+		4
Ben Slimane	33°37′12.54″N 7°9′13.98″W	94				+						+						2
Ben Slimane	33°37′10.68″N 7°9′15.78″W	95		+		+						+						3
Ben Slimane	33°37′3.48″N 7°9′16.44″W	96		+		+						+						3
Ben Slimane	33°36′55.62″N 7°9′13.08″W	97				+						+				+		3
Ben Slimane	33°36′42.84″N 7°8′52.62″W	98				+						+			+			3
Ben Slimane	33°38′25.74″N 7°9′53.46″W	99		+		+						+						3
Ben Slimane	33°37′10.02″N 7°6′44.58″W	100		+								+			+			3
Ben Slimane	33°36′52.80″N 7°6′16.32″W	101	+	+								+			+	+		5
Ben Slimane	33°37′9.78″N 7°5′34.92″W	102	+	+								+						3
Ben Slimane	33°37′9.54″N 7°5′36.90″W	103	+	+		+						+						4
Ben Slimane	33°38′5.28″N 7°5′49.80″W	104	+	+								+			+			4
Ben Slimane	33°38′38.88″N 7°5′33.42″W	105		+		+						+				+		4
Ben Slimane	33°38′47.82″N 7°5′38.34″W	106		+		+						+				+		4
Ben Slimane	33°38′41.88″N 7°5′12.42″W	107				+						+				+		3
Ben Slimane	33°38′36.06″N 7°5′15.00″W	108	+	+		+						+				+		5
Ben Slimane	33°38′29.22″N 7°5′14.28″W	109		+		+						+						3
Ben Slimane	33°38′30.72″N 7°4′55.08″W	110		+		+						+						3
Ben Slimane	33°38′32.82″N 7°2′52.56″W	111		+	+							+			+			4
Ben Slimane	33°38′49.44″N 7°3′14.88″W	112		+		+						+						3
Ben Slimane	33°38′49.74″N 7°3′49.44″W	113	+			+						+						3
Ben Slimane	33°39′17.40″N 7°3′46.20″W	114				+						+						2
Ben Slimane	33°39′30.18″N 7°3′59.22″W	115		+		+						+						3
Ben Slimane	33°40′53.58″N 7°4′40.68″W	116	+	+		+						+			+	+		6
Ben Slimane	33°40′56.64″N 7°4′57.66″W	117		+		+						+						3
Ben Slimane	33°40′57.96″N 7°5′5.34″W	118				+						+						2
Ben Slimane	33°41′0.06″N 7°5′7.80″W	119		+		+						+						3
Ben Slimane	33°41′8.82″N 7°5′19.92″W	120				+						+						2
Ben Slimane	33°41′5.70″N 7°4′36.78″W	121		+		+						+						3
Ben Slimane	33°37′46.32″N 7°6′51.06″W	122	+					+					+					3
Number of populations			36	41	18	39	2	10	4	10	1	72	8	1	24	20	3	109
Occurrence frequency (%)			29.5	33.6	14.8	32.0	1.6	8.2	3.3	8.2	0.8	59.0	6.6	0.8	19.7	16.4	2.5	89.3

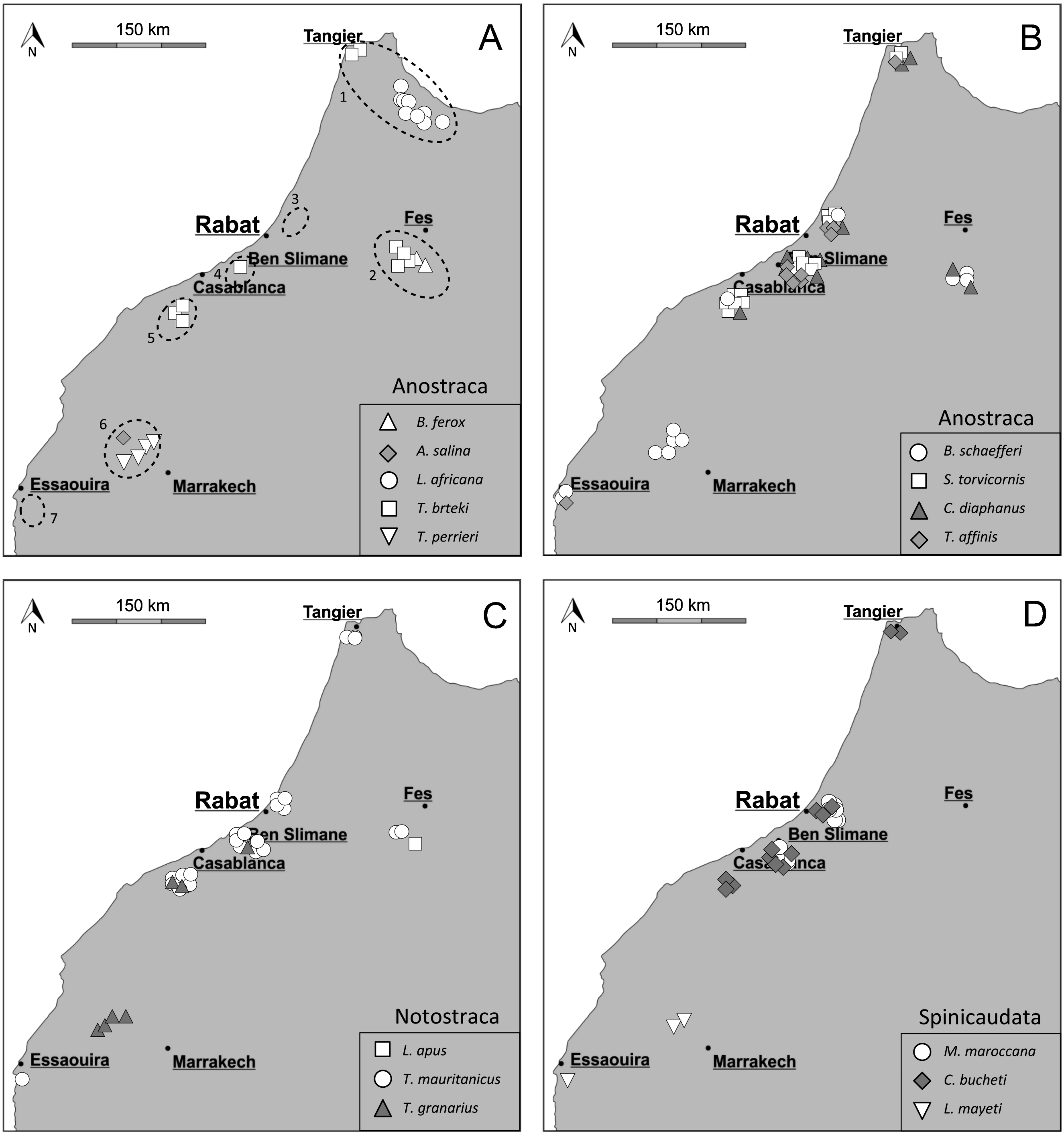

Fig. 1. Distribution and coexistence patterns of large branchiopods in northwestern Morocco. The two top maps (A and B) are representing Anostraca, the bottom left (C) Notostraca and the bottom right (D) Spinicaudata. The study regions are indicated with a dashed oval: Rif (1), Middle Atlas (2), Maamora (3), Ben Slimane (4), Chaouia (5), Jbilets (6) and Essaouira (7). Each symbol represents one pond, but due to the size of the symbols some ponds might overlap.

Thiéry (1987), where it was only recorded in the Middle Atlas as well. An additional recovery of the species in the Chaouia region (Thiéry, 1991), was not confirmed in this study. *Tanymastix affinis* had generally the same distribution as 30 years ago, being present in the coastal regions and the Middle Atlas, but aberrant male morphs were regularly encountered. This deformation of the male clypeus, as also described in Nourisson (1960), may cause confusion in the identification of the species, but is most likely a result of fixation during the molting process (Beladjal and Mertens, 1999). *Eocyzicus saharicus* Gauthier, 1937 and *Phallocryptus spinosa* (Milne-Edwards, 1840) [originally described as

Table 2. Matrix of Fager's affinity indices ($I_{AB} \times 100$) of large branchiopod species in northwestern Morocco.

	C. diaphanus	*B. schaefferi*	*T. affinis*	*B. ferox*	*T. brteki*	*T. perrieri*	*L. africana*	*A. salina*	*T. mauritanicus*	*T. granarius*	*L. apus*	*C. bucheti*	*M. maroccana*	*L. mayeti*
S. torvicornis	33	7	29	0	17	0	0	0	61	18	0	46	32	0
C. diaphanus		10	55	0	8	0	0	0	65	0	0	40	30	0
B. schaefferi			11	10	36	18	0	0	16	31	0	5	11	29
T. affinis				0	0	0	0	0	61	0	0	13	54	0
B. ferox					33	0	0	0	0	0	0	0	0	0
T. brteki						0	0	0	15	22	0	18	0	0
T. perrieri							0	0	0	17	0	0	0	29
L. africana								0	0	0	0	0	0	0
A. salina									0	0	0	0	0	0
T. mauritanicus										5	0	40	37	3
T. granarius											0	13	0	36
L. apus												0	0	0
C. bucheti													18	0
M. maroccana														0

Branchinella spinosa in Thiéry (1987)] were not recovered during our survey. These species were only recorded respectively twice and once in Thiéry (1987). The locations of *E. saharicus* were not rediscovered. *Phallocryptus spinosa* originally coexisted with *A. salina* in pond 73, but may be locally extinct now. Other known locations of *Artemia* were not found. However, another known *Artemia* locality near Asni in the High Atlas mountain region, was found but destroyed by urbanization (observed in July 2013).

In comparison with the historical data from the Chaouia region (Thiéry, 1991), more than half (55%) of the original large branchiopod habitats were destroyed. Also, regional diversity had declined from 11 to seven species and average local diversity had decreased from 4.6 to 2.6 species per pond. However, not all ponds had a lower species richness in comparison with 30 years ago. Two ponds even had a higher species richness, due mainly to *T. cancriformis* and *S. torvicornis* being more common in the Chaouia plains than 30 years ago. Nevertheless, several species have either disappeared or experienced a decline in number of populations: two of the three Spinicaudata species (*L. mayeti* and *M. marrocana*), and most of the *Tr. granarius*, *C. diaphanus* and *B. schaefferi* populations were no longer encountered during our survey. Pond number 59 (number 16 in Thiéry (1991)) was 30 years ago the most diverse pond in the region with 10 coexisting species, which was also the second highest local diversity reported in Africa (Nhiwatiwa et al., 2014). This high diversity site is now drained and leveled (greenfield site). Although the resting egg bank was partly destructed in the process, hatching of the collected sediment nonetheless resulted in the recovery of four species. It is unlikely that we have missed populations during our survey because we repeatedly sampled the active and also hatched the dormant assemblages. The loss of populations and diversity is more likely related to increased anthropogenic impact, mostly due to agriculture and urbanization (several ponds are now greenfield or construction sites). Increased isolation of the ponds can weaken metacommunity dynamics and bad water quality or altered hydroregimes can lead to local extinction, as was also shown for plants in the temporary ponds of the Ben Slimane region (Bouahim et al., 2014).

Table 3. Comparison of the large branchiopod distribution and species richness between Thiéry (1991) and this study. Minus symbols represent the disappearance of species. Plus symbols represent the presence of species (but not in Thiéry, 1991). Equals signs stand for the occurrence in both studies.

Pond nr Thiéry, 1991	Pond nr this study	*S. torvicornis*	*C. diaphanus*	*B. schaefferi*	*T. affinis*	*T. brteki*	*T. perrieri*	*T. mauritanicus*	*T. granarius*	*C. bucheti*	*M. maroccana*	*L. mayeti*	Richness Thiéry, 1991	Richness this study
4	63	+						+	=			−	2	3
5	54	=	−	−	−	−		=	−				7	2
7	55	=	−	−				=	−		−	−	7	2
9	56	+		−				+	−			−	3	2
11	57	+				=		+	−	+			2	4
15	58	=		−				=		+		−	4	3
16	59	=	−	=	−	=	−	=	−	−		−	10	4
18	60	−			−			+					2	1

Conservation Issues

Since MTP and large branchiopods are not included in management and conservation plans or policies in Morocco, a further loss of MTP and their typical inhabitants is to be expected. Large branchiopods play an important role in these temporary ponds as efficient filter feeders, but they are also an important food source for amphibians (Thiéry, 1991) and water birds (Boros et al., 2006; Sánchez et al., 2007). Their decrease may therefore not only affect water quality, but also the food web structure. In some regions, anthropogenic pressure is rapidly growing and impacting the MTP (Bouahim et al., 2011; Rhazi et al., 2012; Bouahim et al., 2014), especially in the continental regions (Ben Slimane, Chaouia, Maamora and some ponds near Tangier) where urbanization and agricultural activities are more intensive than in higher altitude regions. In Morocco, MTP are highly integrated in the daily lives of the local people who use these ponds for cattle (grazing and drinking), harvesting medicinal plants, cultivation and recreation (Bouahim et al., 2011). These ecosystem services may also dwindle with the disappearance of these vulnerable habitats. Moreover, global change may further affect large branchiopod assemblages, as illustrated by the eco-hydrological models of Pyke (2005), Hulsmans et al. (2008) and Tuytens et al. (2014). It is important to understand the effects of these anthropogenic and climatic changes on the pond communities, to develop science based protection measures. To conclude, we suggest greater conservation attention for MTP in general, and for large branchiopods in particular, which may benefit the over-all biodiversity, functioning and ecosystem services of temporary aquatic environments.

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